

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

APPLICATION FOR LETTERS PATENT

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**METHOD OF ADDRESSING MESSAGES AND  
COMMUNICATIONS SYSTEM**

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ATTORNEY'S DOCKET NO. MI40-118

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EM156304204

002720-06E2T960

# METHOD OF ADDRESSING MESSAGES AND COMMUNICATIONS SYSTEM

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## TECHNICAL FIELD

This invention relates to communications protocols and to digital data communications. Still more particularly, the invention relates to data communications protocols in mediums such as radio communication or the like. The invention also relates to radio frequency identification devices for inventory control, object monitoring, determining the existence, location or movement of objects, or for remote automated payment.

## BACKGROUND OF THE INVENTION

Communications protocols are used in various applications. For example, communications protocols can be used in electronic identification systems. As large numbers of objects are moved in inventory, product manufacturing, and merchandising operations, there is a continuous challenge to accurately monitor the location and flow of objects. Additionally, there is a continuing goal to interrogate the location of objects in an inexpensive and streamlined manner. One way of tracking objects is with an electronic identification system.

One presently available electronic identification system utilizes a magnetic coupling system. In some cases, an identification device may be provided with a unique identification code in order to distinguish between a number of different devices. Typically, the devices are entirely passive (have no power supply), which results in a small and portable package. However,

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1 such identification systems are only capable of operation over a relatively  
2 short range, limited by the size of a magnetic field used to supply power to  
3 the devices and to communicate with the devices.

4 Another wireless electronic identification system utilizes a large active  
5 transponder device affixed to an object to be monitored which receives a  
6 signal from an interrogator. The device receives the signal, then generates  
7 and transmits a responsive signal. The interrogation signal and the responsive  
8 signal are typically radio-frequency (RF) signals produced by an RF transmitter  
9 circuit. Because active devices have their own power sources, and do not  
10 need to be in close proximity to an interrogator or reader to receive power  
11 via magnetic coupling. Therefore, active transponder devices tend to be more  
12 suitable for applications requiring tracking of a tagged device that may not  
13 be in close proximity to an interrogator. For example, active transponder  
14 devices tend to be more suitable for inventory control or tracking.

15 Electronic identification systems can also be used for remote payment.  
16 For example, when a radio frequency identification device passes an  
17 interrogator at a toll booth, the toll booth can determine the identity of the  
18 radio frequency identification device, and thus of the owner of the device,  
19 and debit an account held by the owner for payment of toll or can receive  
20 a credit card number against which the toll can be charged. Similarly,  
21 remote payment is possible for a variety of other goods or services.

22 A communication system typically includes two transponders: a  
23 commander station or interrogator, and a responder station or transponder  
24 device which replies to the interrogator.

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1 If the interrogator has prior knowledge of the identification number of  
2 a device which the interrogator is looking for, it can specify that a response  
3 is requested only from the device with that identification number. Sometimes,  
4 such information is not available. For example, there are occasions where  
5 the interrogator is attempting to determine which of multiple devices are  
6 within communication range.

7 When the interrogator sends a message to a transponder device  
8 requesting a reply, there is a possibility that multiple transponder devices will  
9 attempt to respond simultaneously, causing a collision, and thus causing an  
10 erroneous message to be received by the interrogator. For example, if the  
11 interrogator sends out a command requesting that all devices within a  
12 communications range identify themselves, and gets a large number of  
13 simultaneous replies, the interrogator may not be able to interpret any of  
14 these replies. Thus, arbitration schemes are employed to permit  
15 communications free of collisions.

16 In one arbitration scheme or system, described in commonly assigned  
17 U.S. Patent Nos. 5,627,544; 5,583,850; 5,500,650; and 5,365,551, all to  
18 Snodgrass et al. and all incorporated herein by reference, the  
19 interrogator sends a command causing each device of a potentially large  
20 number of responding devices to select a random number from a known range  
21 and use it as that device's arbitration number. By transmitting requests for  
22 identification to various subsets of the full range of arbitration numbers, and  
23 checking for an error-free response, the interrogator determines the arbitration  
24 number of every responder station capable of communicating at the same time.

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1 Therefore, the interrogator is able to conduct subsequent uninterrupted  
2 communication with devices, one at a time, by addressing only one device.

3 Another arbitration scheme is referred to as the Aloha or slotted Aloha  
4 scheme. This scheme is discussed in various references relating to  
5 communications, such as Digital Communications: Fundamentals and  
6 Applications, Bernard Sklar, published January 1988 by Prentice Hall. In this  
7 type of scheme, a device will respond to an interrogator using one of many  
8 time domain slots selected randomly by the device. A problem with the  
9 Aloha scheme is that if there are many devices, or potentially many devices  
10 in the field (i.e. in communications range, capable of responding) then there  
11 must be many available slots or many collisions will occur. Having many  
12 available slots slows down replies. If the magnitude of the number of  
13 devices in a field is unknown, then many slots are needed. This results in  
14 the system slowing down significantly because the reply time equals the  
15 number of slots multiplied by the time period required for one reply.

16 An electronic identification system which can be used as a radio  
17 frequency identification device, arbitration schemes, and various applications for  
18 such devices are described in detail in commonly assigned U.S. Patent  
19 Application Serial Number 08/705,043, filed August 29, 1996, and incorporated  
20 herein by reference.

## 21 22 SUMMARY OF THE INVENTION

23 The invention provides a wireless identification device configured to  
24 provide a signal to identify the device in response to an interrogation signal.

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1 One aspect of the invention provides a method of establishing wireless  
2 communications between an interrogator and individual ones of multiple  
3 wireless identification devices. The method comprises utilizing a tree search  
4 method to establish communications without collision between the interrogator  
5 and individual ones of the multiple wireless identification devices. A search  
6 tree is defined for the tree search method. The tree has multiple levels  
7 respectively representing subgroups of the multiple wireless identification  
8 devices. The method further comprising starting the tree search at a  
9 selectable level of the search tree. In one aspect of the invention, the  
10 method further comprises determining the maximum possible number of  
11 wireless identification devices that could communicate with the interrogator,  
12 and selecting a level of the search tree based on the determined maximum  
13 possible number of wireless identification devices that could communicate with  
14 the interrogator. In another aspect of the invention, the method further  
15 comprises starting the tree search at a level determined by taking the base  
16 two logarithm of the determined maximum possible number, wherein the level  
17 of the tree containing all subgroups is considered level zero, and lower levels  
18 are numbered consecutively.

19 Another aspect of the invention provides a communications system  
20 comprising an interrogator, and a plurality of wireless identification devices  
21 configured to communicate with the interrogator in a wireless fashion. The  
22 respective wireless identification devices have a unique identification number.  
23 The interrogator is configured to employ a tree search technique to determine  
24 the unique identification numbers of the different wireless identification devices

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1 so as to be able to establish communications between the interrogator and  
2 individual ones of the multiple wireless identification devices without collision  
3 by multiple wireless identification devices attempting to respond to the  
4 interrogator at the same time. The interrogator is configured to start the tree  
5 search at a selectable level of the search tree.

6 One aspect of the invention provides a radio frequency identification  
7 device comprising an integrated circuit including a receiver, a transmitter, and  
8 a microprocessor. In one embodiment, the integrated circuit is a monolithic  
9 single die single metal layer integrated circuit including the receiver, the  
10 transmitter, and the microprocessor. The device of this embodiment includes  
11 an active transponder, instead of a transponder which relies on magnetic  
12 coupling for power, and therefore has a much greater range.

#### 13 14 BRIEF DESCRIPTION OF THE DRAWINGS

15 Preferred embodiments of the invention are described below with  
16 reference to the following accompanying drawings.

17 Fig. 1 is a high level circuit schematic showing an interrogator and a  
18 radio frequency identification device embodying the invention.

19 Fig. 2 is a front view of a housing, in the form of a badge or card,  
20 supporting the circuit of Fig. 1 according to one embodiment the invention.

21 Fig. 3 is a front view of a housing supporting the circuit of Fig. 1  
22 according to another embodiment of the invention.  
23  
24



Fig. 4 is a diagram illustrating a tree splitting sort method for establishing communication with a radio frequency identification device in a field of a plurality of such devices.

Fig 5. is a diagram illustrating a modified tree splitting sort method for establishing communication with a radio frequency identification device in a field of a plurality of such devices.

### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

This disclosure of the invention is submitted in furtherance of the constitutional purposes of the U.S. Patent Laws "to promote the progress of science and useful arts" (Article 1, Section 8).

Fig. 1 illustrates a wireless identification device 12 in accordance with one embodiment of the invention. In the illustrated embodiment, the wireless identification device is a radio frequency data communication device 12, and includes RFID circuitry 16. The device 12 further includes at least one antenna 14 connected to the circuitry 16 for wireless or radio frequency transmission and reception by the circuitry 16. In the illustrated embodiment, the RFID circuitry is defined by an integrated circuit as described in the above-incorporated patent application 08/705,043, filed August 29, 1996. Other embodiments are possible. A power source or supply 18 is connected to the integrated circuit 16 to supply power to the integrated circuit 16. In one embodiment, the power source 18 comprises a battery.

The device 12 transmits and receives radio frequency communications to and from an interrogator 26. An exemplary interrogator is described in



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commonly assigned U.S. Patent Application Serial No. 08/907,689, filed August 8, 1997 and incorporated herein by reference. Preferably, the interrogator 26 includes an antenna 28, as well as dedicated transmitting and receiving circuitry, similar to that implemented on the integrated circuit 16.

Generally, the interrogator 26 transmits an interrogation signal or command 27 via the antenna 28. The device 12 receives the incoming interrogation signal via its antenna 14. Upon receiving the signal 27, the device 12 responds by generating and transmitting a responsive signal or reply 29. The responsive signal 29 typically includes information that uniquely identifies, or labels the particular device 12 that is transmitting, so as to identify any object or person with which the device 12 is associated.

Although only one device 12 is shown in Fig. 1, typically there will be multiple devices 12 that correspond with the interrogator 26, and the particular devices 12 that are in communication with the interrogator 26 will typically change over time. In the illustrated embodiment in Fig. 1, there is no communication between multiple devices 12. Instead, the devices 12 respectively communicate with the interrogator 26. Multiple devices 12 can be used in the same field of an interrogator 26 (i.e., within communications range of an interrogator 26).

The radio frequency data communication device 12 can be included in any appropriate housing or packaging. Various methods of manufacturing housings are described in commonly assigned U.S. Patent Application Serial No. 08/800,037, filed February 13, 1997, and incorporated herein by reference.

Fig. 2 shows but one embodiment in the form of a card or badge 19 including a housing 11 of plastic or other suitable material supporting the device 12 and the power supply 18. In one embodiment, the front face of the badge has visual identification features such as graphics, text, information found on identification or credit cards, etc.

Fig. 3 illustrates but one alternative housing supporting the device 12. More particularly, Fig. 3 shows a miniature housing 20 encasing the device 12 and power supply 18 to define a tag which can be supported by an object (e.g., hung from an object, affixed to an object, etc.). Although two particular types of housings have been disclosed, the device 12 can be included in any appropriate housing.

If the power supply 18 is a battery, the battery can take any suitable form. Preferably, the battery type will be selected depending on weight, size, and life requirements for a particular application. In one embodiment, the battery 18 is a thin profile button-type cell forming a small, thin energy cell more commonly utilized in watches and small electronic devices requiring a thin profile. A conventional button-type cell has a pair of electrodes, an anode formed by one face and a cathode formed by an opposite face. In an alternative embodiment, the power source 18 comprises a series connected pair of button type cells. Instead of using a battery, any suitable power source can be employed.

The circuitry 16 further includes a backscatter transmitter and is configured to provide a responsive signal to the interrogator 26 by radio frequency. More particularly, the circuitry 16 includes a transmitter, a

1 receiver, and memory such as is described in U.S. Patent Application Serial  
2 Number 08/705,043.

3 Radio frequency identification has emerged as a viable and affordable  
4 alternative to tagging or labeling small to large quantities of items. The  
5 interrogator 26 communicates with the devices 12 via an electromagnetic link,  
6 such as via an RF link (e.g., at microwave frequencies, in one embodiment),  
7 so all transmissions by the interrogator 26 are heard simultaneously by all  
8 devices 12 within range.

9 If the interrogator 26 sends out a command requesting that all  
10 devices 12 within range identify themselves, and gets a large number of  
11 simultaneous replies, the interrogator 26 may not be able to interpret any of  
12 these replies. Therefore, arbitration schemes are provided.

13 If the interrogator 26 has prior knowledge of the identification number  
14 of a device 12 which the interrogator 26 is looking for, it can specify that  
15 a response is requested only from the device 12 with that identification  
16 number. To target a command at a specific device 12, (i.e., to initiate  
17 point-on-point communication), the interrogator 26 must send a number  
18 identifying a specific device 12 along with the command. At start-up, or in  
19 a new or changing environment, these identification numbers are not known  
20 by the interrogator 26. Therefore, the interrogator 26 must identify all  
21 devices 12 in the field (within communication range) such as by determining  
22 the identification numbers of the devices 12 in the field. After this is  
23 accomplished, point-to-point communication can proceed as desired by the  
24 interrogator 26.

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1 Generally speaking, RFID systems are a type of multiaccess  
2 communication system. The distance between the interrogator 26 and  
3 devices 12 within the field is typically fairly short (e.g., several meters), so  
4 packet transmission time is determined primarily by packet size and baud rate.  
5 Propagation delays are negligible. In such systems, there is a potential for  
6 a large number of transmitting devices 12 and there is a need for the  
7 interrogator 26 to work in a changing environment, where different devices  
8 12 are swapped in and out frequently (e.g., as inventory is added or  
9 removed). In such systems, the inventors have determined that the use of  
10 random access methods work effectively for contention resolution (i.e., for  
11 dealing with collisions between devices 12 attempting to respond to the  
12 interrogator 26 at the same time).

13 RFID systems have some characteristics that are different from other  
14 communications systems. For example, one characteristic of the illustrated  
15 RFID systems is that the devices 12 never communicate without being  
16 prompted by the interrogator 26. This is in contrast to typical multiaccess  
17 systems where the transmitting units operate more independently. In addition,  
18 contention for the communication medium is short lived as compared to the  
19 ongoing nature of the problem in other multiaccess systems. For example,  
20 in a RFID system, after the devices 12 have been identified, the interrogator  
21 can communicate with them in a point-to-point fashion. Thus, arbitration in  
22 a RFID system is a transient rather than steady-state phenomenon. Further,  
23 the capability of a device 12 is limited by practical restrictions on size,  
24 power, and cost. The lifetime of a device 12 can often be measured in

1 terms of number of transmissions before battery power is lost. Therefore,  
2 one of the most important measures of system performance in RFID  
3 arbitration is total time required to arbitrate a set of devices 12. Another  
4 measure is power consumed by the devices 12 during the process. This is  
5 in contrast to the measures of throughput and packet delay in other types of  
6 multiaccess systems.

7 Fig. 4 illustrates one arbitration scheme that can be employed for  
8 communication between the interrogator and devices 12. Generally, the  
9 interrogator 26 sends a command causing each device 12 of a potentially  
10 large number of responding devices 12 to select a random number from a  
11 known range and use it as that device's arbitration number. By transmitting  
12 requests for identification to various subsets of the full range of arbitration  
13 numbers, and checking for an error-free response, the interrogator 26  
14 determines the arbitration number of every responder station capable of  
15 communicating at the same time. Therefore, the interrogator 26 is able to  
16 conduct subsequent uninterrupted communication with devices 12, one at a  
17 time, by addressing only one device 12.

18 Three variables are used: an arbitration value (AVALUE), an  
19 arbitration mask (AMASK), and a random value ID (RV). The  
20 interrogator sends an Identify command (IdentifyCmnd) causing each device of  
21 a potentially large number of responding devices to select a random number  
22 from a known range and use it as that device's arbitration number. The  
23 interrogator sends an arbitration value (AVALUE) and an arbitration mask  
24 (AMASK) to a set of devices 12. The receiving devices 12 evaluate the

1 following equation:  $(AMASK \ \& \ AVALUE) == (AMASK \ \& \ RV)$  wherein "&"  
2 is a bitwise AND function, and wherein "==" is an equality function. If the  
3 equation evaluates to "1" (TRUE), then the device 12 will reply. If the  
4 equation evaluates to "0" (FALSE), then the device 12 will not reply. By  
5 performing this in a structured manner, with the number of bits in the  
6 arbitration mask being increased by one each time, eventually a device 12  
7 will respond with no collisions. Thus, a binary search tree methodology is  
8 employed.

9 An example using actual numbers will now be provided using only four  
10 bits, for simplicity, reference being made to Fig. 4. In one embodiment,  
11 sixteen bits are used for AVALUE and AMASK. Other numbers of bits can  
12 also be employed depending, for example, on the number of devices 12  
13 expected to be encountered in a particular application, on desired cost points,  
14 etc.

15 Assume, for this example, that there are two devices 12 in the field,  
16 one with a random value (RV) of 1100 (binary), and another with a random  
17 value (RV) of 1010 (binary). The interrogator is trying to establish  
18 communications without collisions being caused by the two devices 12  
19 attempting to communicate at the same time.

20 The interrogator sets AVALUE to 0000 (or "don't care" for all bits,  
21 as indicated by the character "X" in Fig. 4) and AMASK to 0000. The  
22 interrogator transmits a command to all devices 12 requesting that they  
23 identify themselves. Each of the devices 12 evaluate  
24  $(AMASK \ \& \ AVALUE) == (AMASK \ \& \ RV)$  using the random value RV that



1 the respective devices 12 selected. If the equation evaluates to "1" (TRUE),  
2 then the device 12 will reply. If the equation evaluates to "0" (FALSE),  
3 then the device 12 will not reply. In the first level of the illustrated tree,  
4 AMASK is 0000 and anything bitwise ANDed with all zeros results in all  
5 zeros, so both the devices 12 in the field respond, and there is a collision.

6 Next, the interrogator sets AMASK to 0001 and AVALUE to 0000 and  
7 transmits an identify command. Both devices 12 in the field have a zero  
8 for their least significant bit, and  $(AMASK \& AVALUE) == (AMASK \& RV)$   
9 will be true for both devices 12. For the device 12 with a random value  
10 of 1100, the left side of the equation is evaluated as follows  $(0001 \&$   
11  $0000) = 0000$ . The right side is evaluated as  $(0001 \& 1100) = 0000$ . The left  
12 side equals the right side, so the equation is true for the device 12 with the  
13 random value of 1100. For the device 12 with a random value of 1010,  
14 the left side of the equation is evaluated as  $(0001 \& 0000) = 0000$ . The right  
15 side is evaluated as  $(0001 \& 1010) = 0000$ . The left side equals the right  
16 side, so the equation is true for the device 12 with the random value of  
17 1010. Because the equation is true for both devices 12 in the field, both  
18 devices 12 in the field respond, and there is another collision.

19 Recursively, the interrogator next sets AMASK to 0011 with AVALUE  
20 still at 0000 and transmits an Identify command.  
21  $(AMASK \& AVALUE) == (AMASK \& RV)$  is evaluated for both devices 12.  
22 For the device 12 with a random value of 1100, the left side of the  
23 equation is evaluated as follows  $(0011 \& 0000) = 0000$ . The right side is  
24 evaluated as  $(0011 \& 1100) = 0000$ . The left side equals the right side, so

15



1 the equation is true for the device 12 with the random value of 1100, so  
2 this device 12 responds. For the device 12 with a random value of 1010,  
3 the left side of the equation is evaluated as  $(0011 \& 0000)=0000$ . The right  
4 side is evaluated as  $(0011 \& 1010)=0010$ . The left side does not equal the  
5 right side, so the equation is false for the device 12 with the random value  
6 of 1010, and this device 12 does not respond. Therefore, there is no  
7 collision, and the interrogator can determine the identity (e.g., an identification  
8 number) for the device 12 that does respond.

9 De-recursion takes place, and the devices 12 to the right for the same  
10 AMASK level are accessed when AVALUE is set at 0010, and AMASK is  
11 set to 0011.

12 The device 12 with the random value of 1010 receives a command and  
13 evaluates the equation  $(AMASK \& AVALUE)=(AMASK \& RV)$ . The left  
14 side of the equation is evaluated as  $(0011 \& 0010)=0010$ . The right side  
15 of the equation is evaluated as  $(0011 \& 1010)=0010$ . The right side equals  
16 the left side, so the equation is true for the device 12 with the random  
17 value of 1010. Because there are no other devices 12 in the subtree, a  
18 good reply is returned by the device 12 with the random value of 1010.  
19 There is no collision, and the interrogator 26 can determine the identity (e.g.,  
20 an identification number) for the device 12 that does respond.

21 By recursion, what is meant is that a function makes a call to itself.  
22 In other words, the function calls itself within the body of the function.  
23 After the called function returns, de-recursion takes place and execution  
24

continues at the place just after the function call; i.e. at the beginning of the statement after the function call.

For instance, consider a function that has four statements (numbered 1,2,3,4) in it, and the second statement is a recursive call.

Assume that the fourth statement is a return statement. The first time through the loop (iteration 1) the function executes the statement 2 and (because it is a recursive call) calls itself causing iteration 2 to occur.

When iteration 2 gets to statement 2, it calls itself making iteration 3.

During execution in iteration 3 of statement 1, assume that the function does a return. The information that was saved on the stack from iteration 2 is loaded and the function resumes execution at statement 3 (in iteration 2), followed by the execution of statement 4 which is also a return statement.

Since there are no more statements in the function, the function de-recurses to iteration 1. Iteration 1, had previously recursively called itself in statement 2. Therefore, it now executes statement 3 (in iteration 1). Following that it executes a return at statement 4. Recursion is known in the art.

Consider the following code which can be used to implement operation of the method shown in Fig. 4 and described above.

1 Arbitrate(AMASK, AVALUE)  
 {  
 2 collision=IdentifyCmnd(AMASK, AVALUE)  
 if (collision) then  
 3 {  
 /\* recursive call for left side \*/  
 4 Arbitrate((AMASK<<1)+1, AVALUE)  
 /\* recursive call for right side \*/  
 5 Arbitrate((AMASK<<1)+1, AVALUE+(AMASK+1))  
 } /\* endif \*/  
 6 } /\* return \*/

7  
 8 The symbol "<<" represents a bitwise left shift. "<<1" means shift  
 9 left by one place. Thus, 0001<<1 would be 0010. Note, however, that  
 10 AMASK is originally called with a value of zero, and 0000<<1 is still 0000.  
 11 Therefore, for the first recursive call, AMASK = (AMASK<<1)+1. So for  
 12 the first recursive call, the value of AMASK is 0000+0001=0001. For the  
 13 second call, AMASK=(0001<<1)+1=0010+1=0011. For the third recursive call,  
 14 AMASK=(0011<<1)+1=0110+1=0111.

15 The routine generates values for AMASK and AVALUE to be used by  
 16 the interrogator in an identify command "IdentifyCmnd." Note that the  
 17 routine calls itself if there is a collision. De-recursion occurs when there is  
 18 no collision. AVALUE and AMASK would have values such as the  
 19 following assuming collisions take place all the way down to the bottom of  
 20 the tree.  
 21  
 22  
 23  
 24

AVALUE	AMASK
0000	0000
0000	0001
0000	0011
0000	0111
0000	1111*
1000	1111*
0100	0111
0100	1111*
1100	1111*

This sequence of AMASK, AVALUE binary numbers assumes that there are collisions all the way down to the bottom of the tree, at which point the Identify command sent by the interrogator is finally successful so that no collision occurs. Rows in the table for which the interrogator is successful in receiving a reply without collision are marked with the symbol "\*". Note that if the Identify command was successful at, for example, the third line in the table then the interrogator would stop going down that branch of the tree and start down another, so the sequence would be as shown in the following table.



1 Arbitrate(AMASK, AVALUE)  
 {  
 2 enqueue(0,0)  
 while (queue != empty)  
 3 (AMASK,AVALUE) = dequeue()  
 collision=IdentifyCmnd(AMASK, AVALUE)  
 4 if (collision) then  
 {  
 5 TEMP = AMASK+1  
 NEW\_AMASK = (AMASK<<1)+1  
 6 enqueue(NEW\_AMASK, AVALUE)  
 enqueue(NEW\_AMASK, AVALUE+TEMP)  
 7 } /\* endif \*/  
 endwhile  
 8  
 9 }/\* return \*/

10 The symbol "!=" means not equal to. AVALUE and AMASK would  
 11 have values such as those indicated in the following table for such code.  
 12

AVALUE	AMASK
0000	0000
0000	0001
0001	0001
0000	0011
0010	0011
0001	0011
0011	0011
0000	0111
0100	0111
...	...

1 Rows in the table for which the interrogator is successful in receiving  
2 a reply without collision are marked with the symbol "\*".

3 Fig. 5 illustrates an embodiment wherein the interrogator 26 starts the  
4 tree search at a selectable level of the search tree. The search tree has a  
5 plurality of nodes 51, 52, 53, 54 etc. at respective levels. The size of  
6 subgroups of random values decrease in size by half with each node  
7 descended. The upper bound of the number of devices 12 in the field (the  
8 maximum possible number of devices that could communicate with the  
9 interrogator) is determined, and the tree search method is started at a level  
10 32, 34, 36, 38, or 40 in the tree depending on the determined upper bound.  
11 In one embodiment, the maximum number of devices 12 potentially capable  
12 of responding to the interrogator is determined manually and input into the  
13 interrogator 26 via an input device such as a keyboard, graphical user  
14 interface, mouse, or other interface. The level of the search tree on which  
15 to start the tree search is selected based on the determined maximum possible  
16 number of wireless identification devices that could communicate with the  
17 interrogator.

18 The tree search is started at a level determined by taking the base two  
19 logarithm of the determined maximum possible number. More particularly, the  
20 tree search is started at a level determined by taking the base two logarithm  
21 of the power of two nearest the determined maximum possible number of  
22 devices 12. The level of the tree containing all subgroups of random values  
23 is considered level zero (see Fig. 5), and lower levels are  
24 numbered 1, 2, 3, 4, etc. consecutively.

22









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1 negative acknowledgment occurs, the device retransmits after a random delay  
2 of an integer number of slot times.

3 Aloha methods are described in a commonly assigned patent application  
4 (attorney docket MI40-089) naming Clifton W. Wood, Jr. as an inventor, titled  
5 "Method of Addressing Messages and Communications System," filed  
6 concurrently herewith, and incorporated herein by reference.

7 In one alternative embodiment, an Aloha method (such as the method  
8 described in the commonly assigned patent application mentioned above) is  
9 combined with determining the upper bound on a set of devices and starting  
10 at a level in the tree depending on the determined upper bound, such as by  
11 combining an Aloha method with the method shown and described in  
12 connection with Fig. 5. For example, in one embodiment, devices 12 sending  
13 a reply to the interrogator 26 do so within a randomly selected time slot of  
14 a number of slots.

15 In another embodiment, levels of the search tree are skipped. Skipping  
16 levels in the tree, after a collision caused by multiple devices 12 responding,  
17 reduces the number of subsequent collisions without adding significantly to the  
18 number of no replies. In real-time systems, it is desirable to have quick  
19 arbitration sessions on a set of devices 12 whose unique identification numbers  
20 are unknown. Level skipping reduces the number of collisions, both reducing  
21 arbitration time and conserving battery life on a set of devices 12. In one  
22 embodiment, every other level is skipped. In alternative embodiments, more  
23 than one level is skipped each time.  
24

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The trade off that must be considered in determining how many (if any) levels to skip with each descent down the tree is as follows. Skipping levels reduces the number of collisions, thus saving battery power in the devices [12]. Skipping deeper (skipping more than one level) further reduces the number of collisions. The more levels that are skipped, the greater the reduction in collisions. However, skipping levels results in longer search times because the number of queries (Identify commands) increases. The more levels that are skipped, the longer the search times. Skipping just one level has an almost negligible effect on search time, but drastically reduces the number of collisions. If more than one level is skipped, search time increases substantially. Skipping every other level drastically reduces the number of collisions and saves battery power without significantly increasing the number of queries.

Level skipping methods are described in a commonly assigned patent application <sup>09/026,045</sup> (attorney docket MI40-117) naming Clifton W. Wood, Jr. and Don Hush as inventors, titled "Method of Addressing Messages, Method of Establishing Wireless Communications, and Communications System," filed <sup>now U.S. Pat. No. 6,072,801,</sup> concurrently herewith, and incorporated herein by reference.

In one alternative embodiment, a level skipping method is combined with determining the upper bound on a set of devices and starting at a level in the tree depending on the determined upper bound, such as by combining a level skipping method with the method shown and described in connection with Fig. 5.

1 In yet another alternative embodiment, both a level skipping method and  
2 an Aloha method (as described in the commonly assigned applications  
3 described above) are combined with the method shown and described in  
4 connection with Fig. 5.

5 In compliance with the statute, the invention has been described in  
6 language more or less specific as to structural and methodical features. It  
7 is to be understood, however, that the invention is not limited to the specific  
8 features shown and described, since the means herein disclosed comprise  
9 preferred forms of putting the invention into effect. The invention is,  
10 therefore, claimed in any of its forms or modifications within the proper  
11 scope of the appended claims appropriately interpreted in accordance with the  
12 doctrine of equivalents.